AD-778 821

UPDATED GUST DESIGN VALUES FOR USE WITH AFFDL-70-106

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Prepared for:

Air Force Dynamics Laboratory

November 1973

UNCLASSIFIED
Security Classification

AD 778 821

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Aeronautical Research Associates of Princeton, Inc., 50 Washington Road, Princeton, New Jersey 08540	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

"UPDATED GUST DESIGN VALUES FOR USE WITH AFFDL-70-106"

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report - 1 March 1973 to 1 November 1973.

5. AUTHOR(S) (First name, middle initial, last name)

John C. Houbolt

6. REPORT DATE November 1973	7a. TOTAL NO. OF PAGES 43	7b. NO. OF REFS 19

8a. CONTRACT OR GRANT NO. F33615-73-C-3048	9a. ORIGINATOR'S REPORT NUMBER(S) A.R.A.P. No. 204
b. PROJECT NO. 1367	
c. Task No. 136702	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFFDL-TR-73-148
d.	

10. DISTRIBUTION STATEMENT

"Approved for public release; distribution unlimited"

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY AF Flight Dynamics Laboratory Air Force Systems Command Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

Further efforts are made by this report to establish better representative parameters applicable to the mathematical modeling of atmospheric turbulence and to establish associated design values for the structural design of aircraft due to gusts.

An evaluation is made of the results that are presented in AGARD Report No. 586-71, which summarizes an extensive data gathering program of gust loads on many aircraft. Updated gust design values and curves are developed herein. These design values were used in a separate study which was made as a check validation of the gust design procedures that are outlined in an Air Force Technical Report, AFFDL-TR-70-106, and which was conducted on several specific existing aircraft. The report covering the validation serves as a companion to this report.

A new, very streamlined procedure for designing aircraft due to gusts is also developed herein.

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DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Gust Design Procedures						
Power Spectral Techniques						
Atmospheric Turbulence						
Aircraft Dynamic Response						
Gust Intensities						
Exceedance Curves						

UNCLASSIFIED

Security Classification

☆U.S.Government Printing Office: 1974 — 759-433/532

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FOREWORD

This report was prepared by Aeronautical Research Associates of Princeton, Inc., Princeton, New Jersey, under Air Force Contract F33615-73-C-3048. The contract was initiated under Project No. 1367, Task No. 136702, "Engineering Support for the Validation of New Gust Design Procedures." The work was administered under the direction of the Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, Mr. Paul L. Hasty (AFFDL/FBE), Project Engineer.

The work reported in this study was conducted by Aeronautical Research Associates of Princeton, Inc. with Dr. John C. Houbolt as principal investigator, and covers the period 1 March 1973 to 1 November 1973. The report was submitted by the author in November 1973.

The contractor's report number is A.R.A.P. 204.

This technical report has been reviewed and is approved.

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INTRODUCTION

The purpose of this report is to update the gust design values and curves that are developed in reference 1. The updating was to be based on two principal sources: (1) newer gust data that have been collected and analyzed since reference 1 was issued, particularly that given in reference 2, and (2) the validation check of the gust design procedures that are suggested in reference 1 that was carried out simultaneously with this effort by the Lockheed Aircraft Corporation on four Lockheed model aircraft, the C-130, C-141A, C-140, and C-5A, reference 3. The basic notions behind the validation check were to check on the soundness of the gust design procedures suggested in reference 1, and to provide a base for changing design values if so indicated.

It is to be noted that great hope was placed in reference 2 as a source of yielding much more reliable turbulence parameters than heretofore establish, due to the fact that the report represented a unique coverage of many thousands of hours of flight of several aircraft. Most previous reports have dealt largely with the analysis of only a few hours of flight data (such as 5, 13, 47 hours) and statistical reliability of the results is low. Several of the aircraft covered in reference 2 have many hours of flight data, and it was therefore expected that the data for these aircraft were of good statistical reliability and dependability. It is one of the greatest disappointments the author has encountered to find that very little use could be made of the data presented. The next section indicates some of the reasons why the data of reference 2 are not of direct value to derive gust design parameters or curves.

SECTION II

THE DEDUCTION OF TURBULENCE PARAMETERS

As is well known, a popular way to represent gust load exceedances is by means of the equation

$$\frac{N}{N_o} = P_1 e^{-\frac{x}{A\sigma_1}} + P_2 e^{-\frac{x}{A\sigma_2}} \tag{1}$$

and to give tabulations of the proportion of time in turbulence parameters P_1 and P_2, and severity parameters σ_1 and σ_2 as a function of altitude. The scale of turbulence L, which is needed in the evaluation of the structural parameter A, and the characteristic frequency N_o is also indicated as a function of altitude.

It is perhaps also well known that the author has never been satisfied with the manner by which this equation is used and, in particular, with how the parameters P_1, P_2, σ_1 and σ_2 are deduced. There are many reports which deal with the deduction of these parameters. References 4-19 are some. Figure 1 indicates the range of values that have been deduced. for P_1 and P_2, and figure 2 pertains to σ_1 and σ_2. It is seen that the range in values of the P's is greater than an order of magnitude, while the values of the σ's differ by up to a factor 3 (because of the exponential variation indicated in equation (1), the results for N/N_o are extremely sensitive to the values of σ used).

There are many reasons why the spread shown in figures 1 and 2 occurs. Main reasons are because the interpretation of flight data is very subjective, and because no consistent procedure has been used in analyzing flight data; the results indicated by data depends very much on the individual making the analysis, and on the particular response results he uses in evaluating the data.

One specific reason for the cause in spread of data shown in figures 1 and 2 is illustrated in figure 3. In the consideration of flight exceedance data, say in the range of high load levels, one individual may draw curve a, while another curve b. Note, both curves represent the data well out in the range of large load values, the range which is significant for static design. The deduced values of P_2 and σ_2 are vastly different, however, for the two curves. Figure 3(b) shows typically the variation of P_2 and σ_2 that is found in a specific case, depending on how the tail of the data is fitted by an exponential curve (straight line on the semilog plot shown). Any point on the curve of figure 3(b) will yield a curve which "fits" the high end of the data reasonably well;

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thus, from the same data, values of P_2 may differ by an order of magnitude, or σ_2 may differ by 50% or more depending on the interpretation of the individual making the determination. Other specific reasons why large spreads in the deduced values of P and σ are found include:

1) The use of different analytical treatments to establish the response parameters A and N_0 ; some analyses are based on single-degree-of-freedom response, others use multimode response treatments. Single-degree-of-freedom treatments even have various degrees of approximations, and response values obtained from them may vary considerably. The multimode treatments vary with respect to modal content, some may use 3, others 6, while others may include as high as 20 modes.

2) The use of different scale values L , which has a pronounced effect and the A value evaluated.

3) The use of different cut-off frequencies in the evaluation of the integrals defining A and N_0 .

4) The data sample is far too small in terms of hours of flight represented (it is senseless to analyze 10 hours of data when thousands of hours are needed to give representative statistical averages).

In brief, no consistent approach has been used in the deductions of the turbulence parameters P_1 , P_2 , σ_1 and σ_2 .

A scheme advocated by the author for establishing the generalized exceedance curves is depicted by figure 4. First, A and N_0 values should be derived in a consistent way for all aircraft considered, such as through use of the charts that are presented in reference 1. The charts in this reference, as with similar charts developed by other individuals, may not be correct on all counts, but their sole use would at least place the treatment of all aircraft on a consistent basis. With A and N_0 found, we then convert the data to generalized exceedance form, specifically in the form of N/N_0 vs. x/A . The results from various aircraft may show scatter, such as depicted by the four curves shown, but this scatter is to be expected and is not to be of concern. Instead of deriving the P and σ values for each curve, we simply draw a curve representing the average of all the curves shown, such as the heavy curve shown on the figure. We then use this average curve as the generalized exceedance curve for design purposes. Note, we have not derived any P or σ values; they are not needed. The deduced exceedance curve is all that is needed. (There is no point in taking curves, deriving P and σ values, and then to use these P and σ values to re-establish a curve, especially when the P and σ values deduced are so questionable.)

SECTION III

THE DATA OF REFERENCE 2

Some comments are given in this section regarding the utility of exceedance data presented in reference 2. Although the comments are for the most part not favorable from the point of view of design use, it is to be noted that no slight is meant at the author of the report. He was under the guidance of a group of advisors, and followed their instructions admirably. The advice given by the advisors doesn't appear to have been the best possible and, thus, unfortunately, the results presented in the paper aren't very useful, as was hoped they would be.

Some of the reasons the data in reference 2 are subject to suspect are as follows. The values of A and N_0 were computed by different individuals for differing sophistication in response analysis, ranging from 1 to 30 degrees-of-freedom. Differing scale values and differing cut-off frequencies in the evaluation of A and N_0 were also used. Thus, no consistency is to be found in the evaluation of A and N_0. The exceedances are expressed in exceedances per nautical mile times a ratio N_0'/N_0, which involves the zero crossing values for gusts as well as for response. No use can be made of exceedance values expressed in this way. An attempt was made to convert the curves to the more meaningful form of N/N_0 expressed in terms of x/A, but it became impossible to establish newer and consistent values of A and N_0 to make this conversion because information on flight parameter values (weights, velocities, slope of the lift curve) were not available.

Some examples are given to point out the uncertainty of the data presented. Both the C-130 and C-141A had thousands of hours of data. It might be expected that because of the very large data sampling, similar turbulence parameters would be indicated from the data of these two aircraft. The results shown, however, indicate very large differences in the parameters. If the results given in reference 2 are to be believed, in fact, then one must conclude that no sense will ever be made out of atmospheric turbulence parameters. To illustrate this point specifically, consider figure 5. This figure shows, for example, the exceedance curves for the C-130 and C-141A airplane for the altitude bracket of 15,000-20,000 ft. Note, both airplanes had 2000 hours of flight in this altitude range, and for nearly the same type route service, and for nearly uniform flight exposure throughout the year. The exceedance intercept for $\frac{x}{A} = 0$ is related to the proportion of time in turbulence (P_1 as used in equation (1)). Note, however, an order of

magnitude difference is indicated. The slope of the curves in the lower range of x/A establishes σ_1 ; values indicated are $\sigma_1 = 3.4$ fps by the C-130 and $\sigma_1 = 2.6$ by the C-141A, representing a very significant difference. If we say that perhaps errors in determining N_0'/N_0 cause the apparent difference in P_1 values, and adjust the curves to have the same exceedance intercept, figure 5(b), then we see that the x/A values are quite different. We then might question whether the A values used cause this difference.

Attempts were made to check on the validity of the A values that were used in deducing the results given in reference 2. The values of A and N_0 were re-evaluated according to the procedure given in reference 1 in an attempt to convert the exceedance curves to the more appropriate N/N_0 vs. x/A form. Sample results for the A values are shown in figure 6; the solid curves represent the results that are derived from the procedures of reference 1, the dashed curves give the values of A that were used in deducing the curves presented in reference 2. It is noted that the A values used in reference 2 are markedly different than those predicted by use of reference 1, and in many cases the trend is not even correct. The vast difference of the results shown in figure 6 is one of the reasons why the exceedance curves given in reference 2 are subject to question. Conversion of the curves to supposedly more correct values was not possible because certain quantities such as the weight and velocity values were not known. A complete reanalysis starting with the raw data is needed to put the curves on a firmer, more consistent basis.

Figure 7 shows the values of P_1 (or at least the relative values) and the values of σ_1 as a function of altitude, as deduced from the C-130 and C-141A exceedance curves given in reference 2, on the assumption that the curves are correct. We note the large difference in the results; the question naturally arises, which, if any, of the results are correct. The nature of the results shown in figures 5, 6 and 7 makes it hopeless to use the data of reference 2 to deduce turbulence parameters. In principle, the results shown in figure 6 for the two airplanes should be the same. The fact that they are not indicates that there is still much about airplane response parameters and about the deduction of atmospheric turbulence parameters that we don't understand.

SECTION IV

UPDATED EXCEEDANCE CURVES

The gust design curves that were used in the check validation that is described in reference 3 are presented in this section. Unfortunately, it must be admitted that the curves do not emanate from a firm and sound data base, because the present state of knowledge of turbulence parameters is not good enough to make this possible. The curves are derived in part by using the results that are indicated in a rough or broad sense by previous studies, and in part by considering what experience indicates the answers should be.

Figure 8 is a key figure used in the derivation of the updated exceedance curves presented herein. The design gust values x/A for $N_o = 1$ given by curve a is here assumed to be given by a normal distribution curve with the peak value at an altitude of 20,000 ft; specifically, the curve is given by

$$\frac{x}{A} = 66\ e^{-a(h-20)^2}$$

where altitude h is in thousands of feet and a = .000343 . The numerical values in this equation were chosen so as to give the equivalent gust velocity values given by curve b, where

$$\left(\frac{x}{A}\right)_e = \sqrt{\frac{\rho}{\rho_o}}\ \frac{x}{A}$$

A comparison of curve b with other $\left(\frac{x}{A}\right)_e$ values used or suggested is shown in figure 9. We note that curve b is simply a compromise of other suggested $\left(\frac{x}{A}\right)_e$ curves. The value of $\frac{x}{A} = \left(\frac{x}{A}\right)_e = 57.5$ for h = 0 is chosen because gust velocity values in this range are required in the spectral approach (due to differences in K_ϕ and K_g) to give acceleration results which are comparable to those given by the 50 fps design gust velocity used in the discrete-gust approach (reference 1). The derivation of the curves for other values of N_o on figure 8 will be discussed subsequently. In actuality, figure 8 represents a complete entity for the static strength design of aircraft to gusts; no further charts or discussion relative to σ and P values are needed.

The updated load exceedance curves that are presented herein are constructed as follows, on the basis of the information given in figure 8, and the P and σ values shown in figure 10 and 11. The P_1 curve shown in figure 10 was established as follows. For altitudes lower than 10,000 ft, there is at least

unanimity of various results that P_1 behaves roughly as shown. Above 10,000 ft, many results indicate that P_1 seems to be roughly constant up to about 30-40,000 ft. A mean value of all results of around .05 was therefore selected for this altitude band (see figure 1). The P_1 values above 40,000 ft are largely a guess, although U-2 results, if they can be believed, indicate a variation as shown, (see ref. 18).

Some results indicate a decreasing σ_1 value with increasing altitude; some an increasing value, but all roughly in the neighborhood of 3 fps, figure 2. A value of $\sigma_1 = 3$ fps for all altitudes was therefore selected, figure 11. With the P_1 and σ_1 values of figures 10 and 11, the first part of the generalized load exceedance curves may be constructed using the first term on the right-hand side of equation (1).

It is reasoned that severe turbulence associated with strong convection or with storms should appear equally at altitudes up to the average height of thunderstorms of around 35-40,000 ft. A constant value of .005, roughly representing the mean of all previous results, figure 1, was therefore chosen for this range. Also, for values above 40,000 ft, as well as for the range of 10,000 to 40,000, it was assumed that P_2 should be simply $.01P_1$. The specification of P_2 fixes the N/N_o intercept value for $\frac{x}{A} = 0$ for the exponential function which represents the tail or high x/A values of the exceedance curves (the second term of equation (1)). This tail may be fixed to a specific position by specifying a second point through which the tail should pass. Herein, this second point is defined such that the values of x/A given in figure 8 for $N_o = 1$ are all assumed to occur at the same exceedance rate of $N = 7 \times 10^{-8}$. Values of σ_2 that follow from this construction are shown in figure 11.

The complete generalized load exceedance curves that are found by the process described in the preceding paragraphs are shown in figure 12. These curves may be used to establish the relative severity of various missions, or to derive representative fatigue loading curves for experimental tests. Reference 1 suggests that the static design of aircraft to gust should be based on the fact that the exceedance rate for limit load encounter should never be greater than a specified value, regardless of the altitude of flight. This concept is still advocated herein. If we chose $N \leq 7 \times 10^{-8}$, then the exceedance curves of figure 12 yield the various curves shown in figure 8 for values of N_o other than 1.

The updated gust design curves in the form of N_o vs. x/A, as suggested in reference 1, are shown in figure 13. These curves represent an alternative form of the design data given on figure 8, or they are equivalently derivable from figure 12 on the assumption that limit load encounter should never exceed a rate of $N = 7 \times 10^{-8}$, regardless of the altitude of flight.

SECTION V

EFFECT OF REFERENCE 3 ON THE PROCEDURES RECOMMENDED IN REFERENCE 1

Comments made by various individuals, and the work covered in reference 3, indicate that the procedures recommended in reference 1 form, in general, a good base for the design of aircraft due to gusts. Two improvements are indicated, however, both of which are quite logical. One is relative to the use of 1-g level flight stresses as basic reference stresses, the other is related to the composite approach suggested in reference 1; these two points are discussed more fully in the following.

Preliminary design.- Because the load distribution over the wing depends somewhat on the load factor the airplane experiences, it is better to use stresses per incremental g of maneuver, rather than the level flight 1-g stresses, for calculation purposes; thus, x_{1-g} in equation (33) of reference 1 should be replaced by x_M, where x_M denotes the stress due to a 1-g incremental maneuver.

The steps (here abbreviated) of the preliminary - and perhaps final - design check thus read as follows:

1. List various possible conditions of flight involving altitude, speed, weight, and weight distribution.

2. Select points throughout the structure that are suspected of being critical locations.

3. Establish values of the stress per g of incremental maneuver, x_M, at these locations for the various flight conditions.

4. By figures 14 and 15 (figures 17 and 18 of reference 1), establish the values of A_r and N_0 at each of the chosen flight conditions.

5. With the x_M values of step 3 and the A_r's of step 4 determine the values of A by the relation

$$A = A_r x_M$$

For aircraft with large flexible swept wings, the slope of the lift curve used in step 4 should be that for the flexible airplane, both in determining μ and A_r, so that the load effects due to wing bending are approximately taken into account. Note the intent of considering various flight conditions is to find the condition which leads to the largest value of A at each altitude for the particular response quantity of concern.

6. For each structural point being checked and each altitude, take the largest value of A found, multiply by 1.1 and divide the resulting value into $x_L - x_{1-g}$ to form the effective x/A values as follows

$$\frac{x}{A} = \frac{x_L - x_{1-g}}{1.1A_r x_M}$$

where x_L is the limit load value, and x_{1-g} is the 1-g flight stress. The factor 1.1 is introduced as a means for approximately taking into account the amplification effects due to flexibility. The factor is a rough average value; if judgment or some previous results indicate that a different factor may be in order, the number may be adjusted upward or downward accordingly.

7. Enter figure 13 (updated version of figure 23 of reference 1) with the N_o and x/A values established in steps 4 and 6 and compare each point with the appropriate altitude curve. Decide action according to the rules given in reference 1.

Composite approach.- The composite approach outlined in reference 1 was based on c-g vertical acceleration. Since some of the larger accelerations may occur without inducing the more severe or design stresses, as in the case of small loading in the fuselage, the use of a composite c-g acceleration is not really appropriate for a design check. The results given in reference 3 illustrate that the use of a composite acceleration leads to results that have little practical design significance. The composite approach may be tailored to a useful purpose, however, if expressed in terms of stress, rather than acceleration. Thus, equation (35) of reference 1 should be replaced by

$$\sigma_{x_n} = A_r x_M \sigma_2$$

where σ_2 is given by figure 11 (the σ_2 value replaces the σ_w value given by figure 21 of reference 1), and σ_{x_n} denotes the rms stress value for the nth segment. With this change, and the use of

$$\frac{x_L - x_{1-g}}{1.1\sigma_x}$$

for the effective $\frac{x}{\sigma_x}$ value, where σ_x is the composite rms stress, as obtained by equation (38) in reference 1, the composite approach proceeds as otherwise outlined in reference 1.

A main feature of this composite approach is that it gives some consideration to aircraft utilization. Suppose, for

example, that 5 categories of utilization of the aircraft under consideration are envisioned. Suppose, further, that the use of the preliminary design approach indicated that 4 of the categories were not gust critical, and that these 4 categories represented 95 percent of the anticipated aircraft utilization, but the 5th category, representing only a 5 percent aircraft utilization, was found to be gust critical. The question that is faced is: should the aircraft be designed for gusts due to a category of utilization which represents only 5 percent of the aircraft use? The composite approach is a means for answering this question, since it gives due consideration to aircraft utilization and yields results representing a "weighted average."

SECTION VI

SIMPLIFIED GUST DESIGN CHARTS

Convenient charts were given in reference 1 for establishing the gust response parameters A_r and N_o for rigid body vertical acceleration; these charts are reproduced here as figures 14 and 15. In making use of these figures, and in the course of establishing gust design borders, such as represented by figure 13, it was discovered that a remarkably streamlined rigid body gust design procedure could be developed in which there was no necessity at all to evaluate the structural parameters A_r and N_o. The essence of this development is given in this section.

Consider the second term of equation (1), which dictates the values of N/N_o in the large value or design range of x/A. Reference 1 shows that the response parameters A_r and N_o, for an assumed rigid body aircraft with the degree of freedom of vertical motion only, can be established through the use of figures 14 and 15 by the equations

$$A_r = \eta \frac{V}{cg} \frac{K_\phi}{\mu} \tag{2}$$

$$N_o = \frac{V}{\pi c} k_o \tag{3}$$

The parameter η in A_r is introduced as an approximate way for taking into account flexible body amplification effects; thus, it is assigned values such as 1.1, 1.15, or whatever might be felt appropriate, depending on the experience gained on the aircraft configuration under study. The substitution of these terms in the second term of equation (1) gives the following equation applicable at large $\Delta n/A_r$ values

$$N = \frac{V}{\pi c} k_o P_2 e^{-X} \tag{4}$$

where

$$X = \frac{\Delta n/\eta}{\frac{V}{cg} \frac{K_\phi}{\mu} \sigma_2}$$

We note that if the mass parameter μ is specified, then by charts 14 and 15, the values of K_ϕ/μ and k_o both become specified. If we also introduce the design exceedance rate of $N \leq 7\times10^{-8}$, as specified previously in this report, and use specified P_2 and σ_2 values such as are given by figures 10

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and 11, then it may be noted that all quantities are fixed except for $\Delta n/\eta$ and V/c . A simple gust design border relating $\Delta n/\eta$ to V/c is therefore indicated by equation (4). Figure 16 gives such results for altitudes of $h = 0$ and 20,000 ft as established by the P_2 and σ_2 values of figures 10 and 11, and the N curves of figure 12.

By means of results of the type shown in figure 16, gust design, or at least a preliminary design evaluation, is extremely simplified. The following example is given by way of illustration. Suppose that the following parameters apply to an airplane under study,

h	μ	$\frac{V}{c}$	$\frac{2L}{c}$
0	10	20	100
20,000	18	30	100

and that a value of $\eta = 1.1$ is assumed. For these values, figure 16 yields

$$\Delta n = 1.57 \quad \text{for} \quad h = 0$$

and

$$\Delta n = 1.99 \quad \text{for} \quad h = 20{,}000$$

We treat these load factor increments as though produced by a pull-up maneuver; thus, if the airplane can withstand a load factor of 2.57 at $h = 0$ and 2.99 for $h = 20{,}000$, for the loading condition being studied, then it should be safe for gust encounter. The design for gusts is thus made exceedingly easy.

SECTION VII

DISCUSSION AND RECOMMENDATIONS

The validation check described in reference 3 and which made use of the gust design curves developed herein appears in general to substantiate the gust design procedures that are recommended in reference 1. Gust design based on the concept that limit load exceedance rate should not exceed a specified value regardless of the altitude of flight, and which leads to design borders of gust design velocity x/A vs. N_O for various altitudes, is still preferred over a mission analysis approach. The main attributes of a mission analysis approach is to establish how one mission may compare to another with respect to general load severity, and to establish representative load exceedance curves for fatigue testing.

A reanalysis of the flight data presented in reference 2 to yield generalized exceedance curves in the form of N/N_O vs. x/A would be highly desirable. This reanalysis should be made using a consistent method for evaluating the A and N_O parameters, such as outlined in reference 1, and should be made only for the aircraft which have many hours of flight data (C-130, C-141A, B-52, and B-58). There is still something mysterious about the scale of turbulence L, and the response parameters A and N_O for various aircraft. The results shown in reference 2 indicate that the gust loads flight data for the C-130 and C-141A lead to markedly different load exceedance curves for comparable flight conditions (like altitudes and route). The wing loading on the two airplanes are roughly the same, and the main parameter that is used in response evaluation that appears different for the two aircraft is the wing chord, the chord of the C-141A being about twice that of the chord of the C-130. In an attempt to establish why the generalized load exceedance curves indicated by the two aircraft differ, and to try to understand response behavior better, it is considered highly desirable to fly these two aircraft side by side through various turbulence patches (as a means for assuring that the turbulence encounter is the same) and then to determine the generalized exceedance curves to see if a difference is still noted. Such an experiment should provide a clue as to what may be wrong with present techniques for analyzing turbulent flight data.

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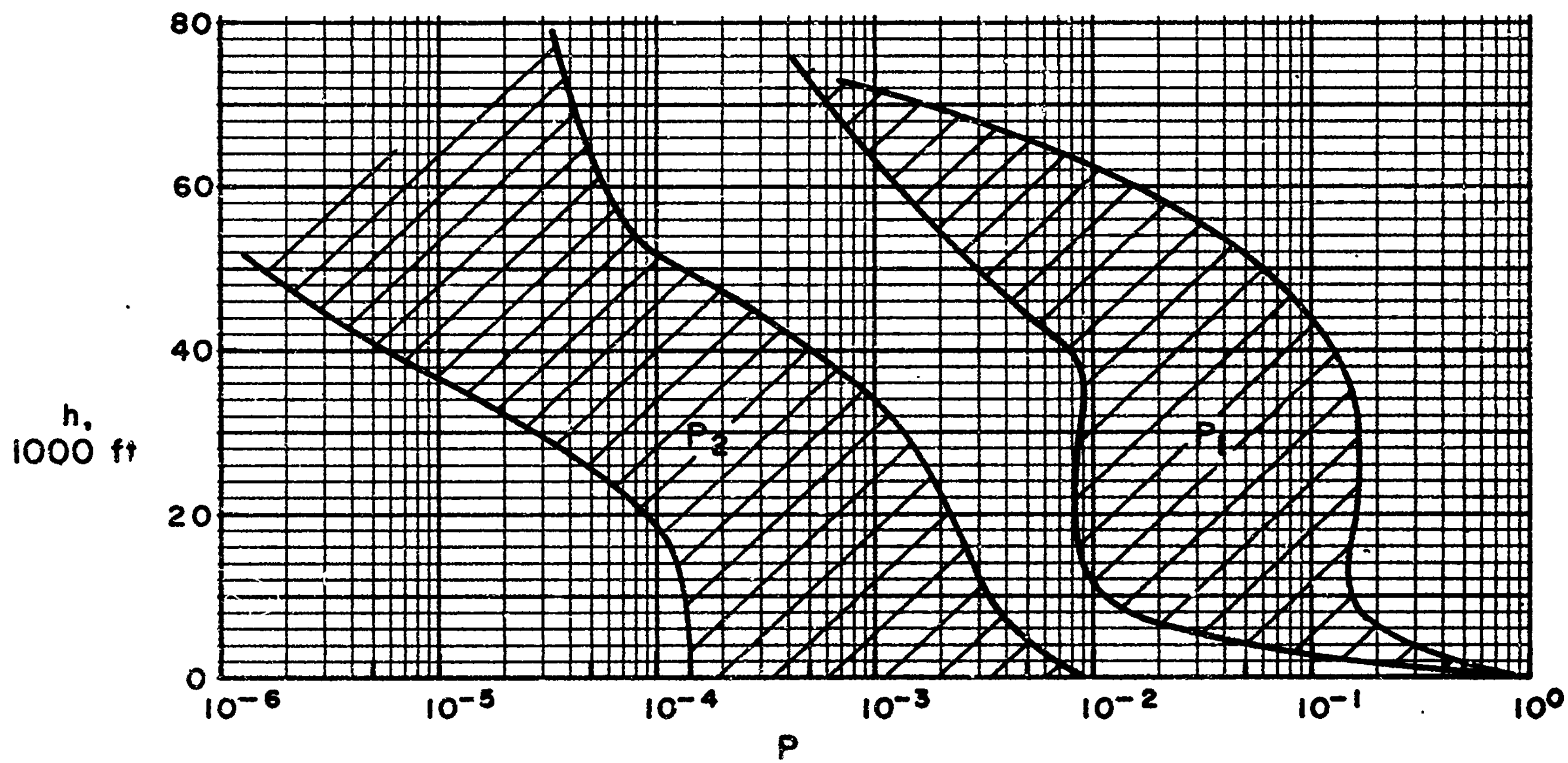


Figure 1. Range of P_1 and P_2 values indicated by various studies

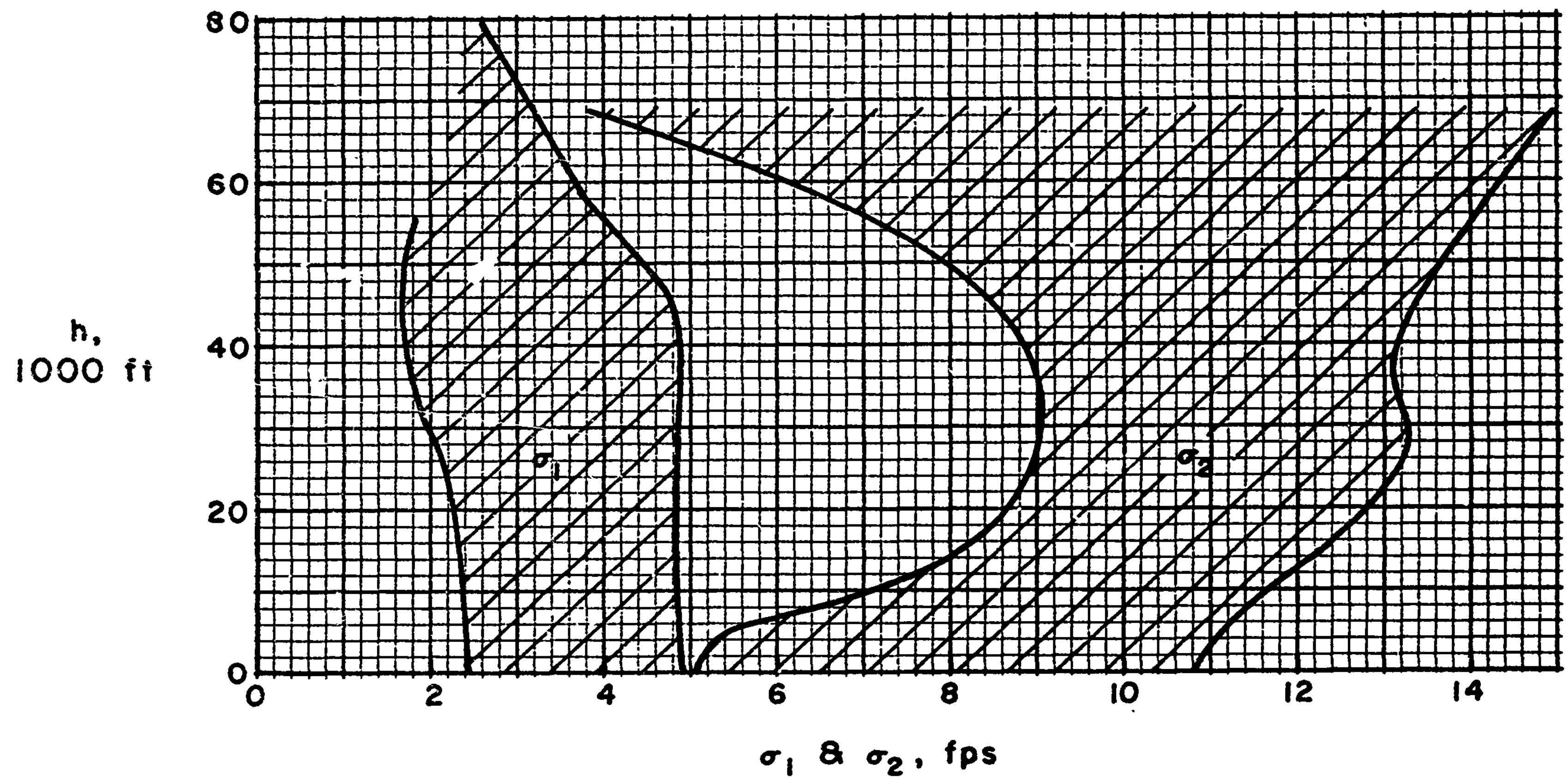


Figure 2. Range in σ_1 and σ_2 values indicated by various studies

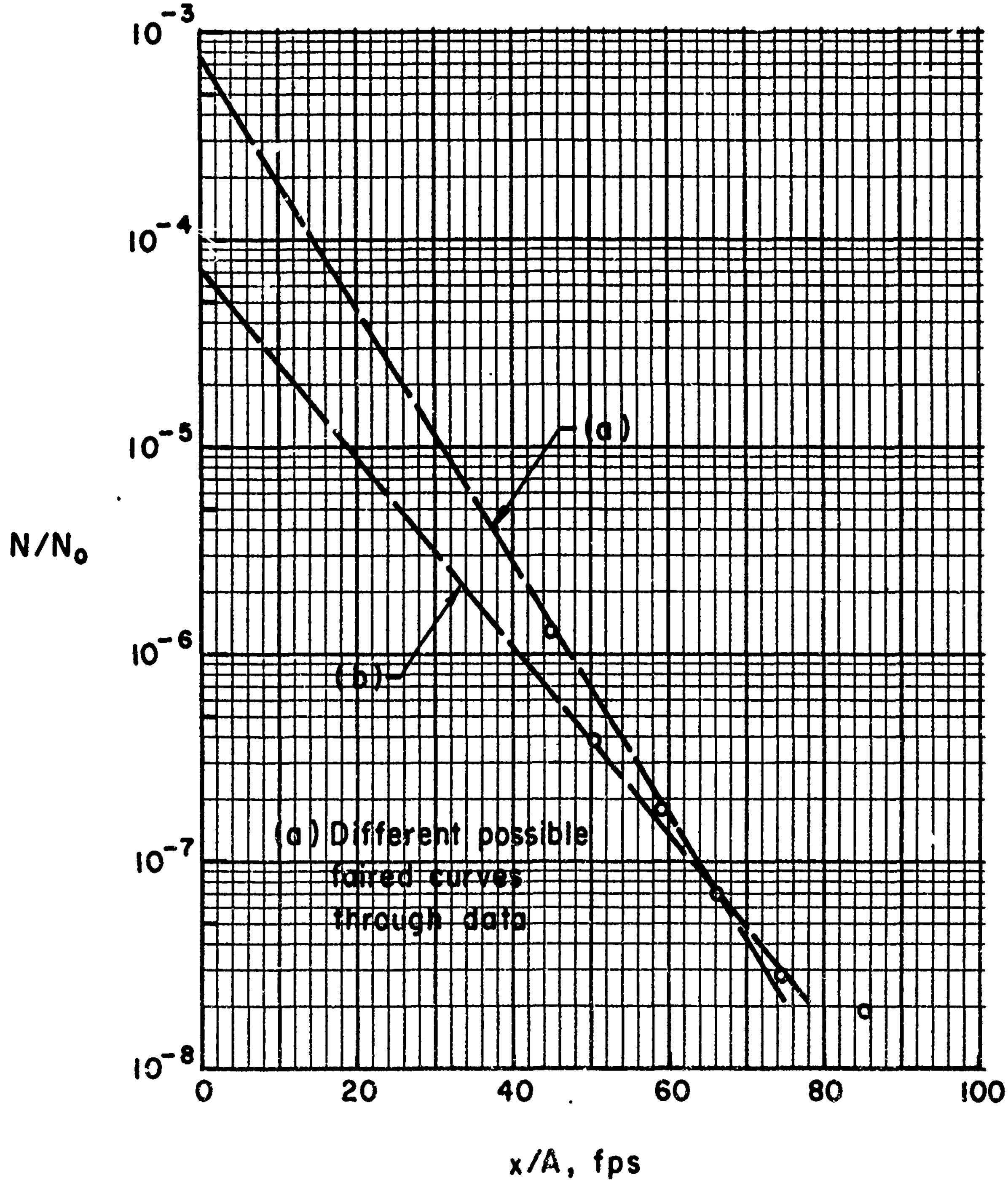


Figure 3. Different fairings of gust data and their effect on the deduced P_2 and σ_2 values

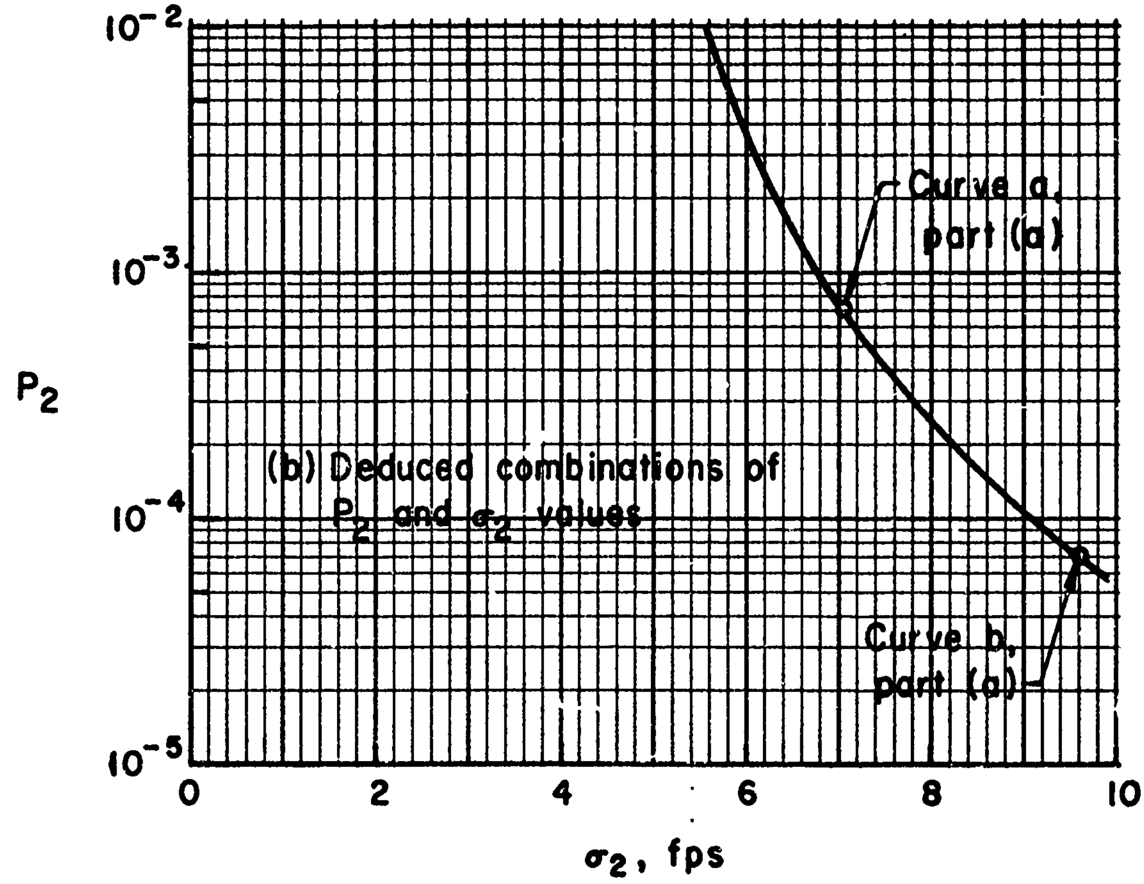


Figure 3. (concluded)

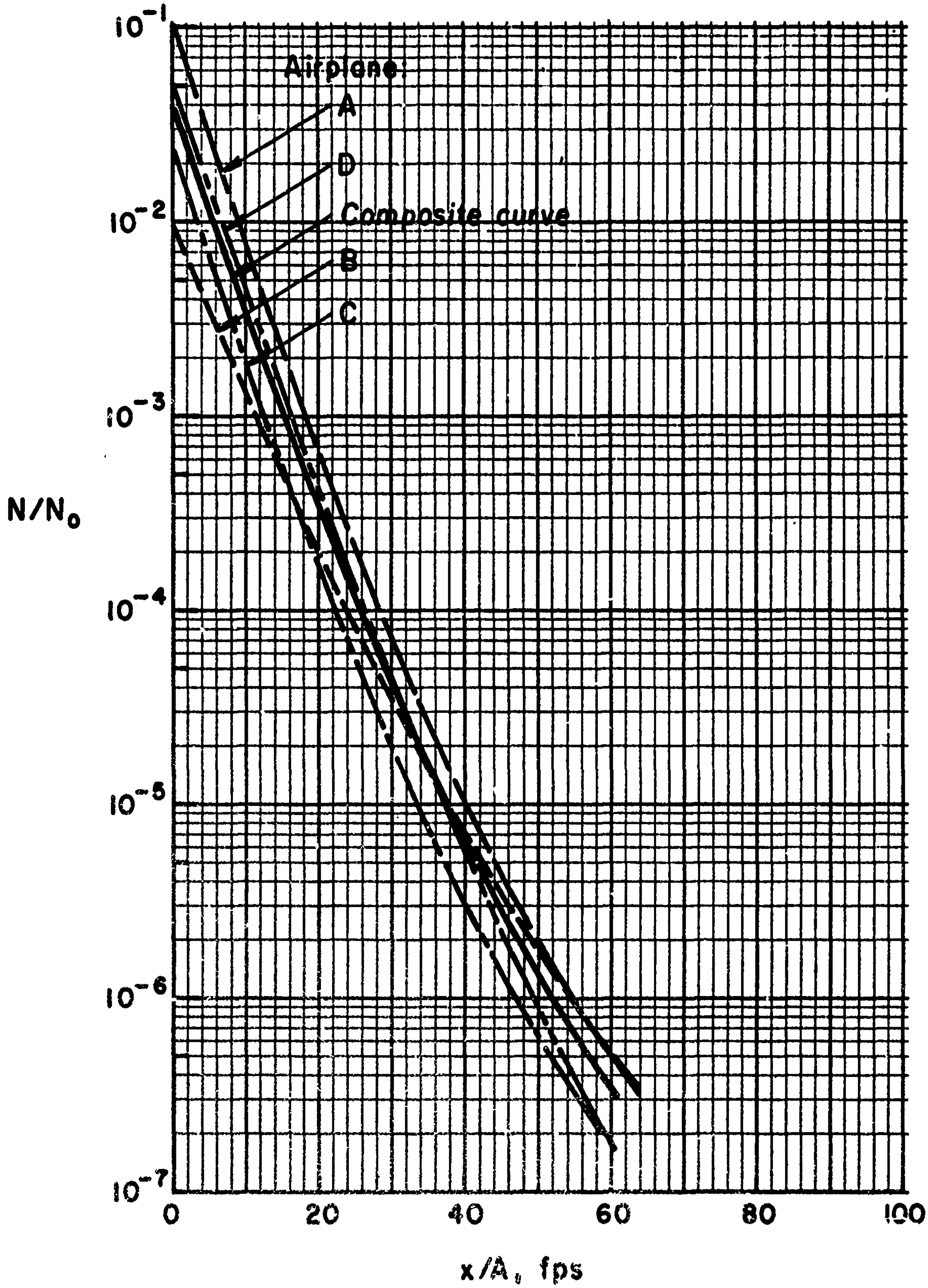


Figure 4. Illustration of suggested improved way to establish generalized gust load exceedance curves

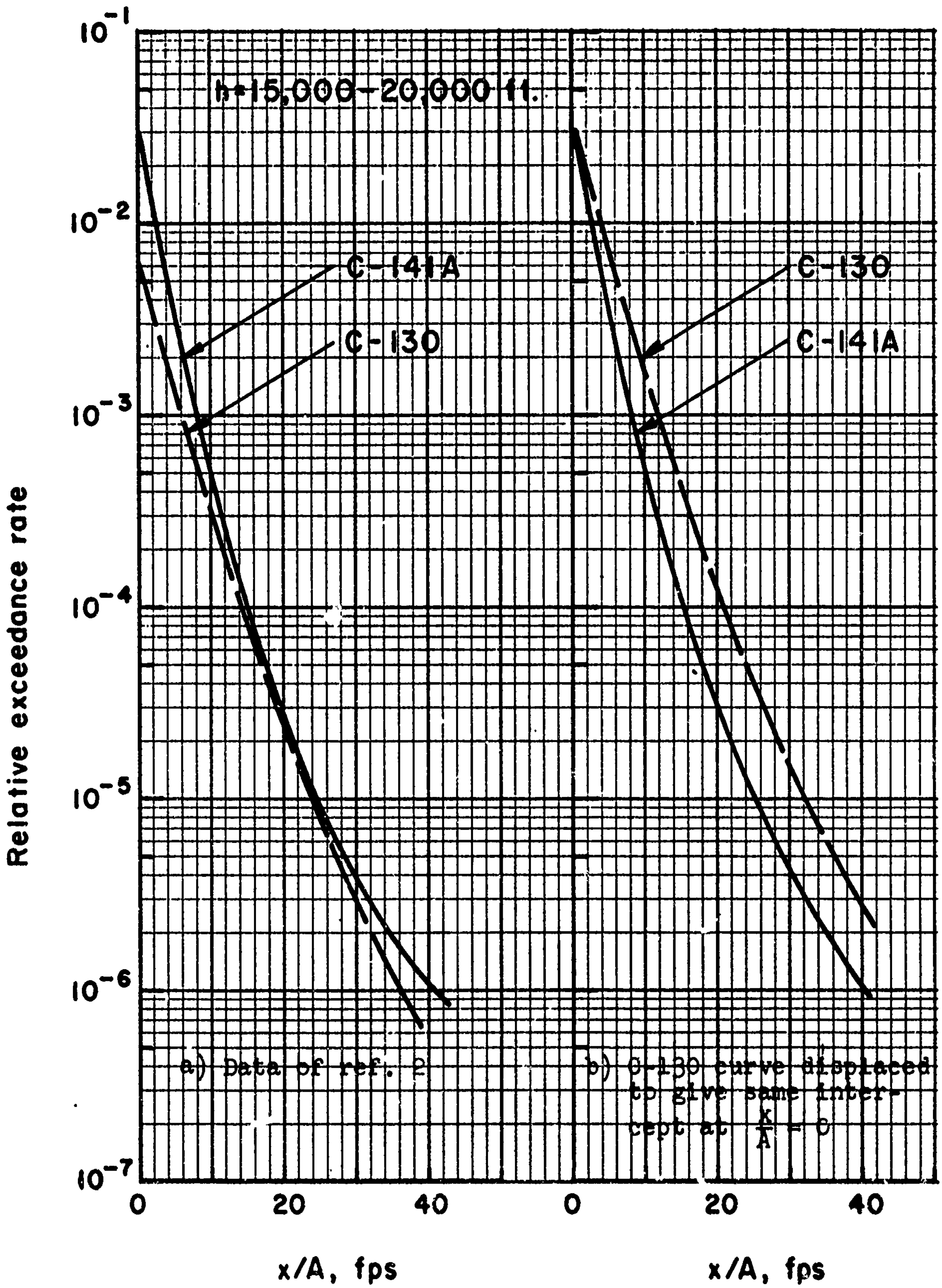


Figure 5. Exceedance results given in ref. 2 for the C-130 and C-141A for the same altitude range of 15,000-20,000

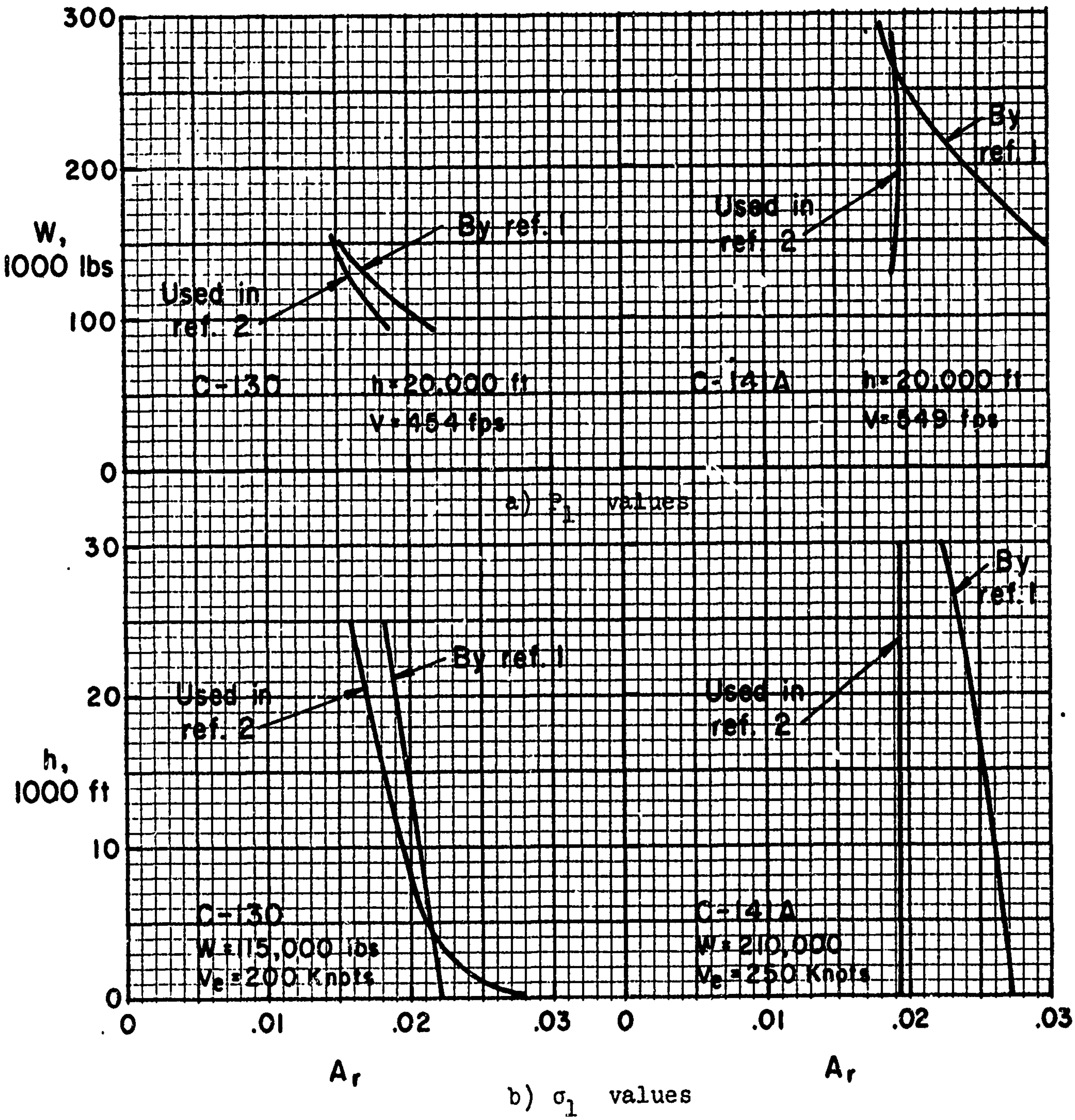
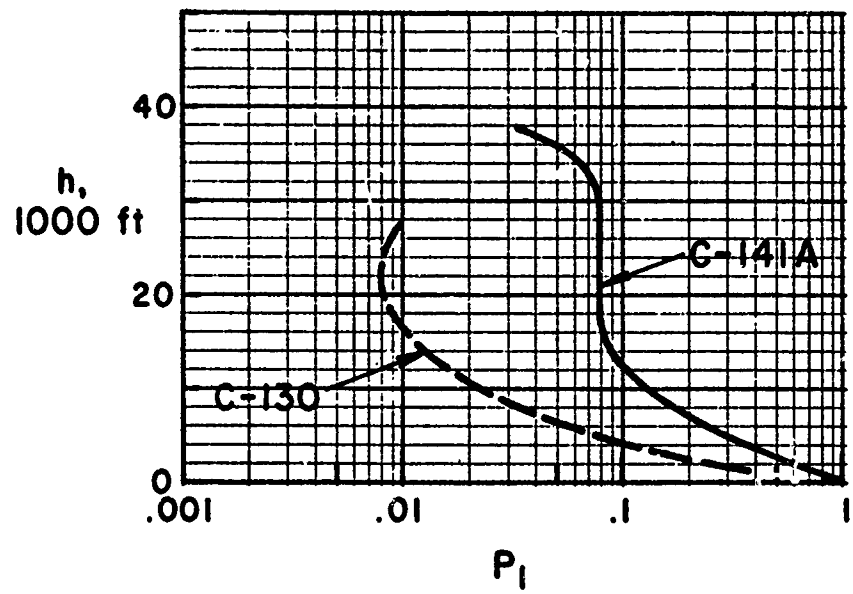
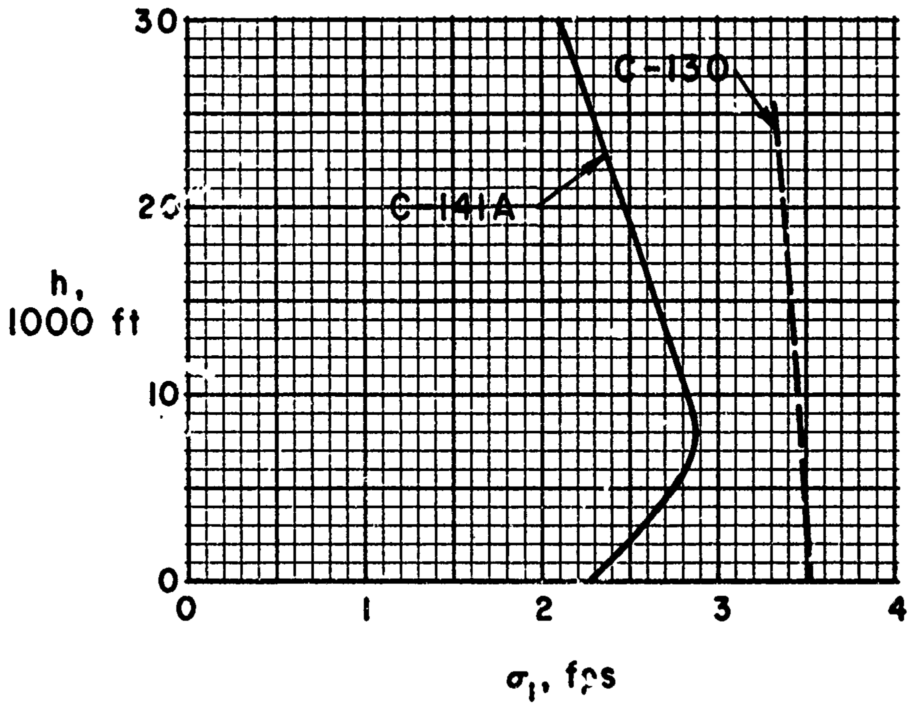


Figure 6. Comparison of A values derived from ref. 1 with those used in ref. 2



a) P_1 values



b) σ_1 values

Figure 7. The P_1 and σ_1 values deduced from ref. 2 for the C-130 and C-141A airplanes

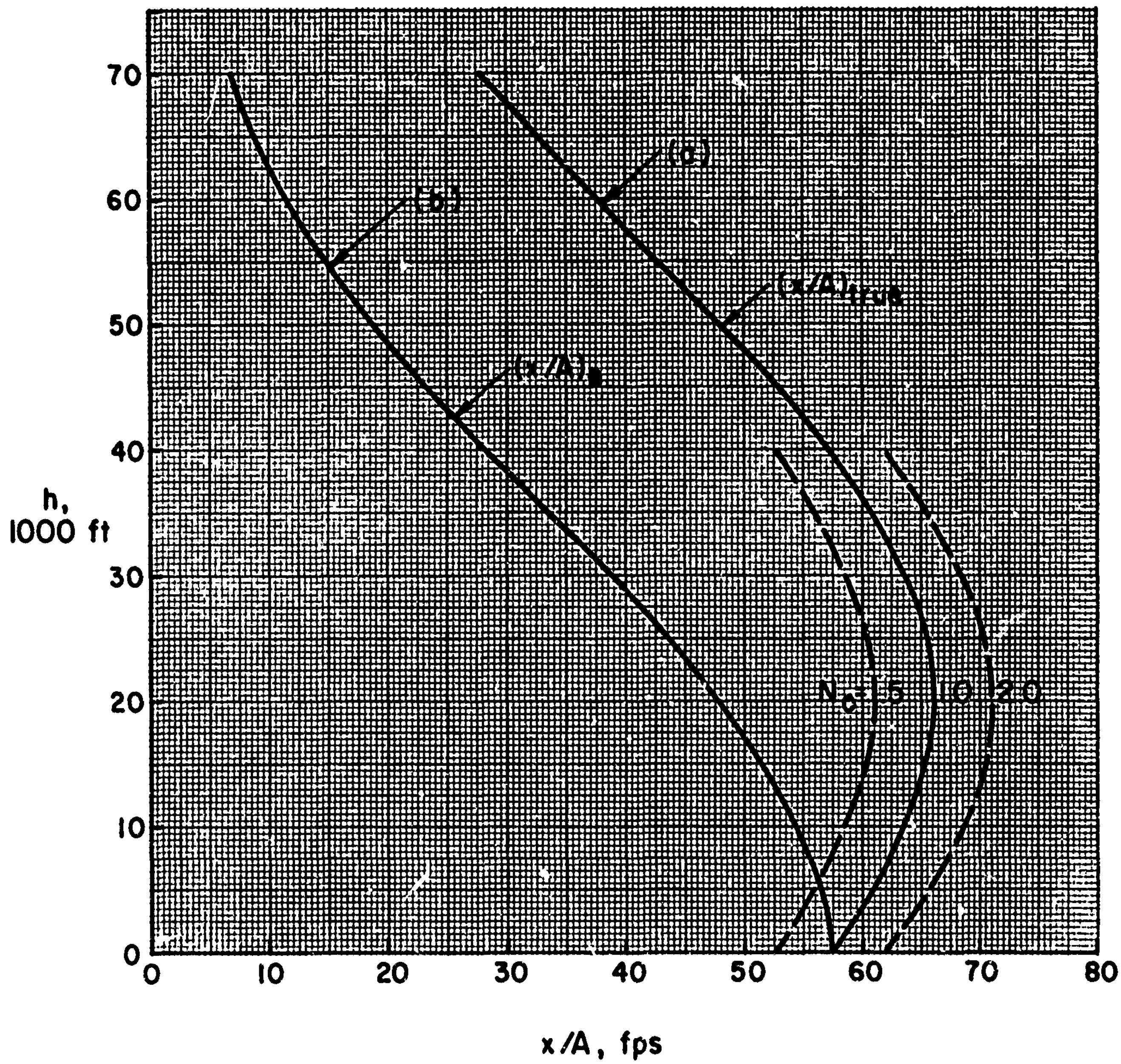


Figure 8. Limit load gust design values x/A as a function of altitude

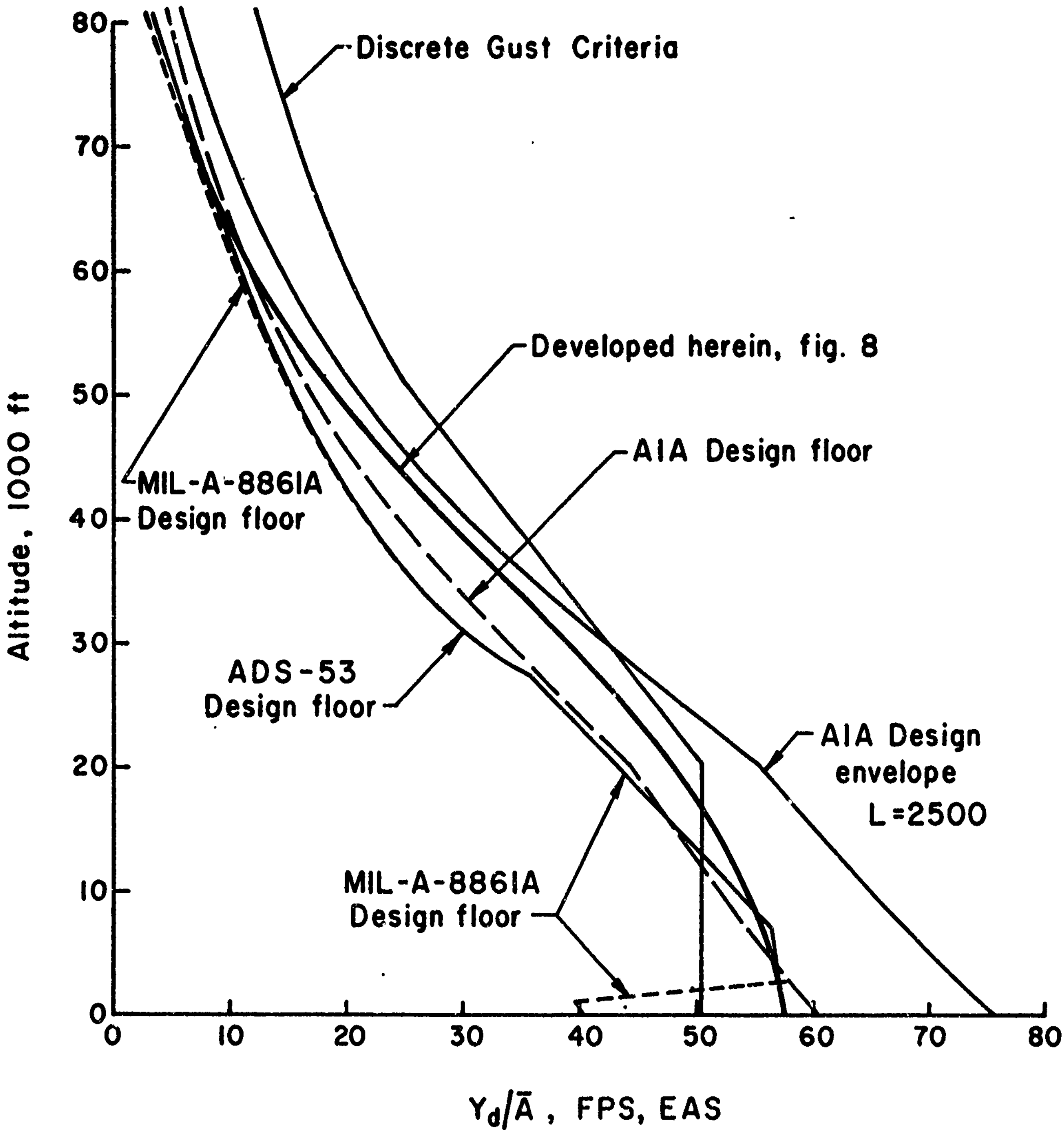


Figure 9. Comparison of $\left(\frac{x}{A}\right)_e$ from various sources

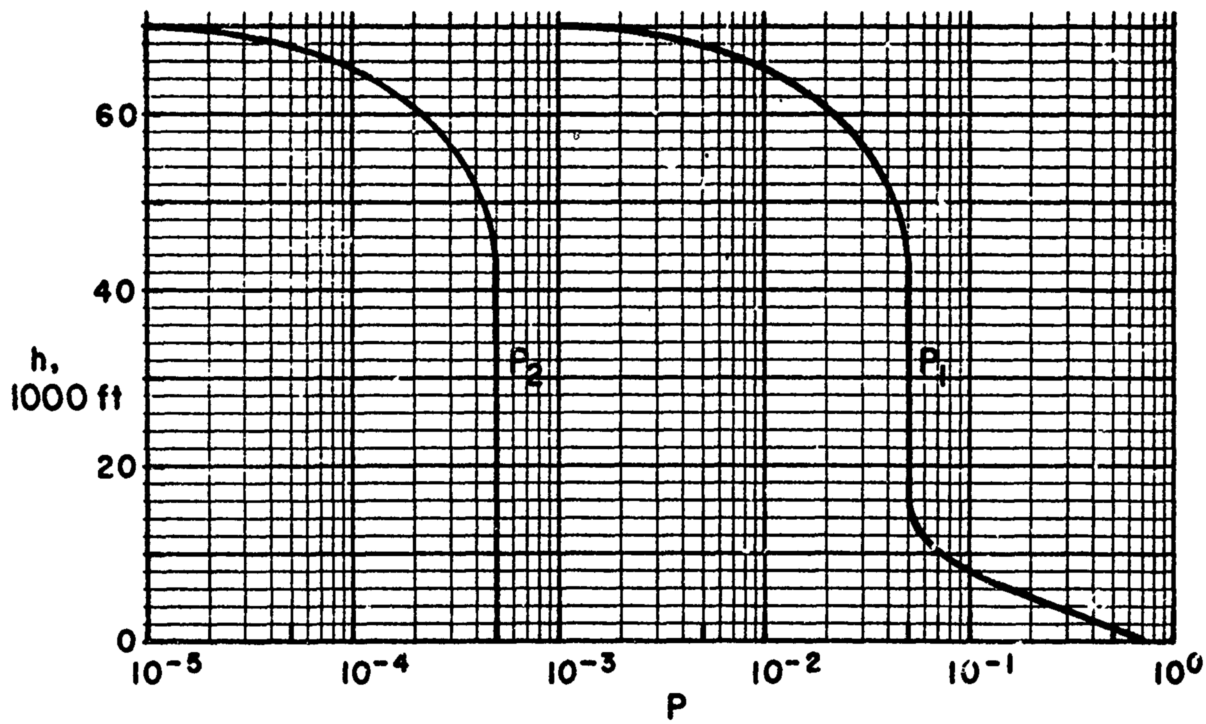


Figure 10. Updated P_1 and P_2 values

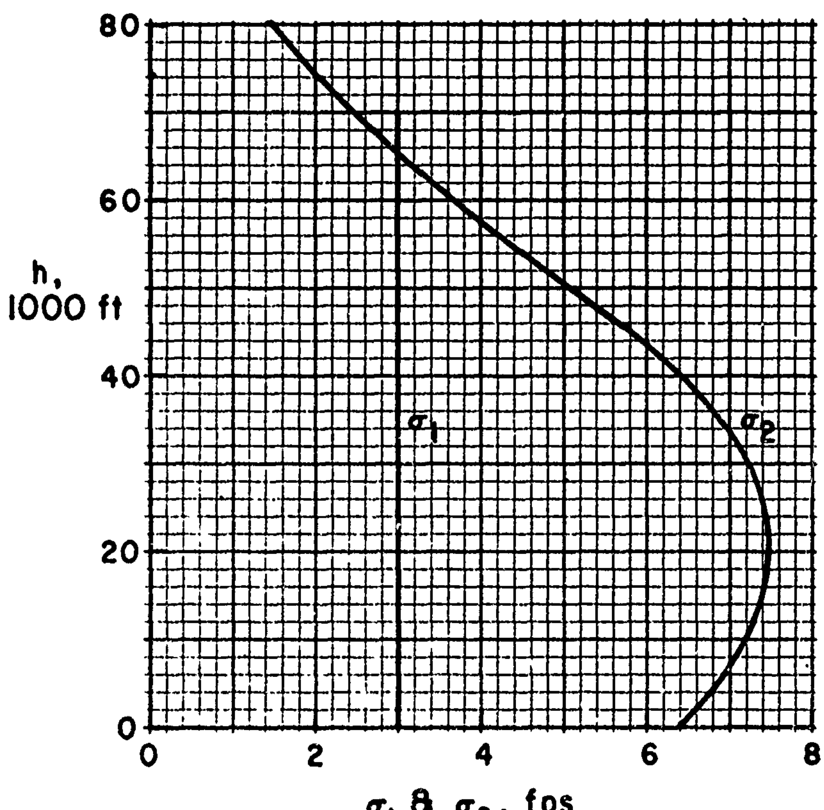


Figure 11. Updated σ_1 and σ_2 values

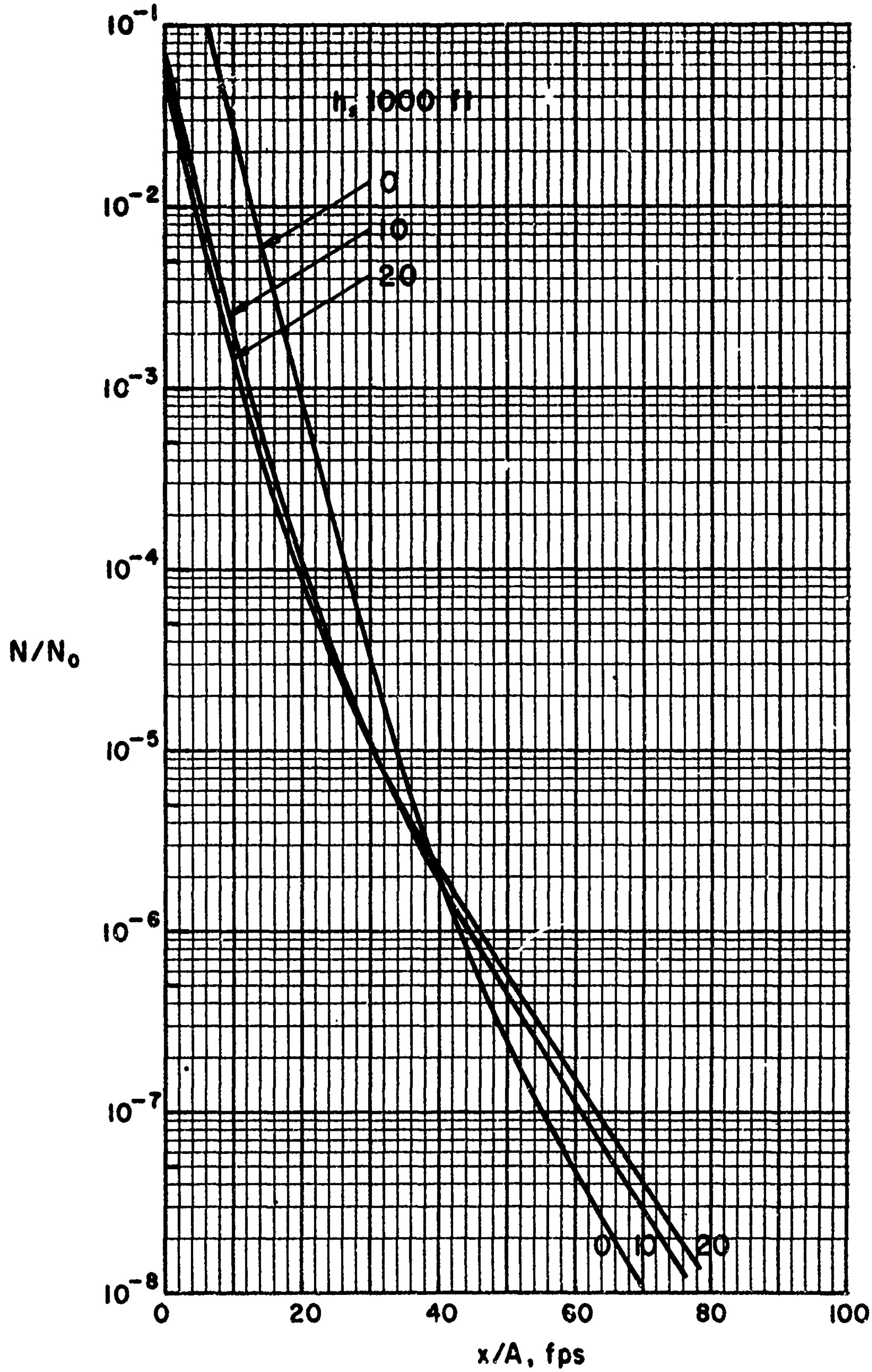


Figure 12. The updated generalized exceedance curves

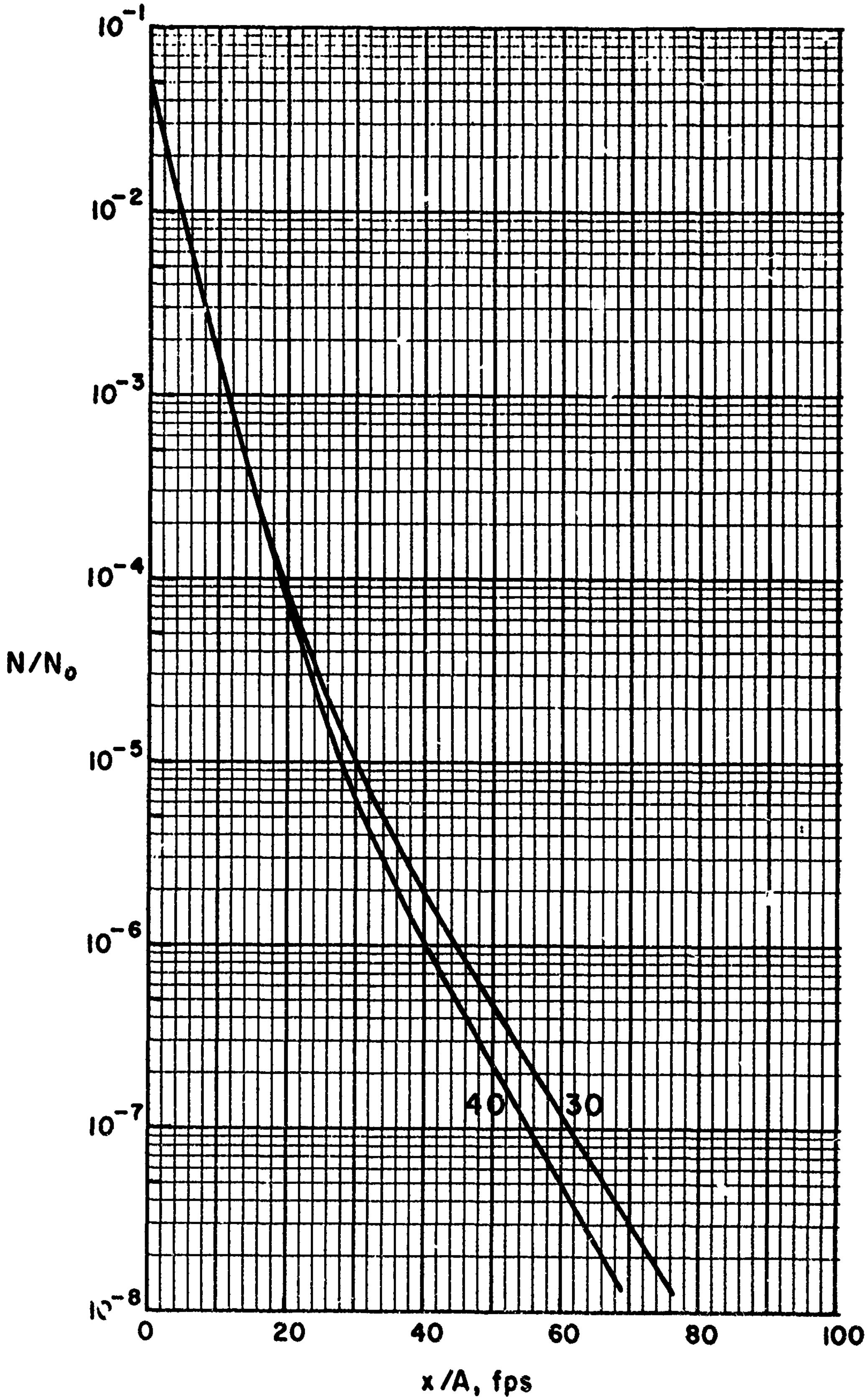


Figure 12. (continued)

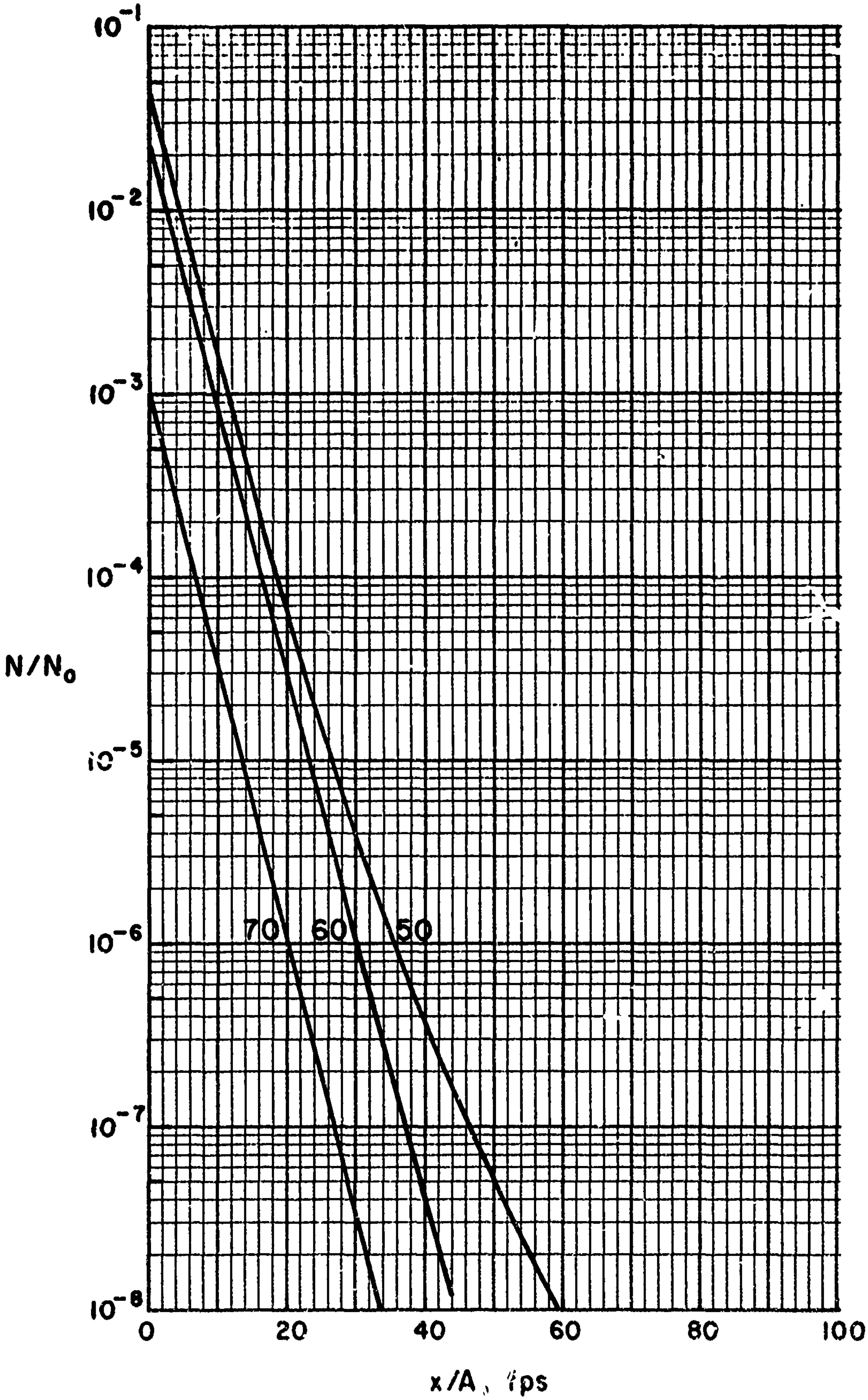


Figure 12. (concluded)

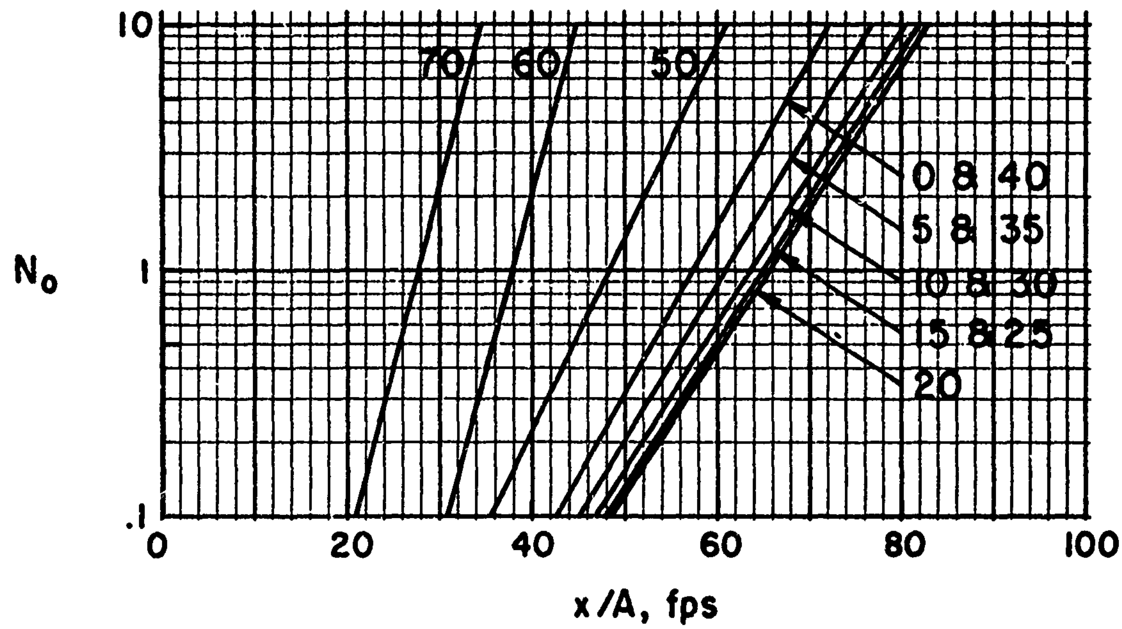


Figure 13. Gust design borders in terms of N_o vs. x/A

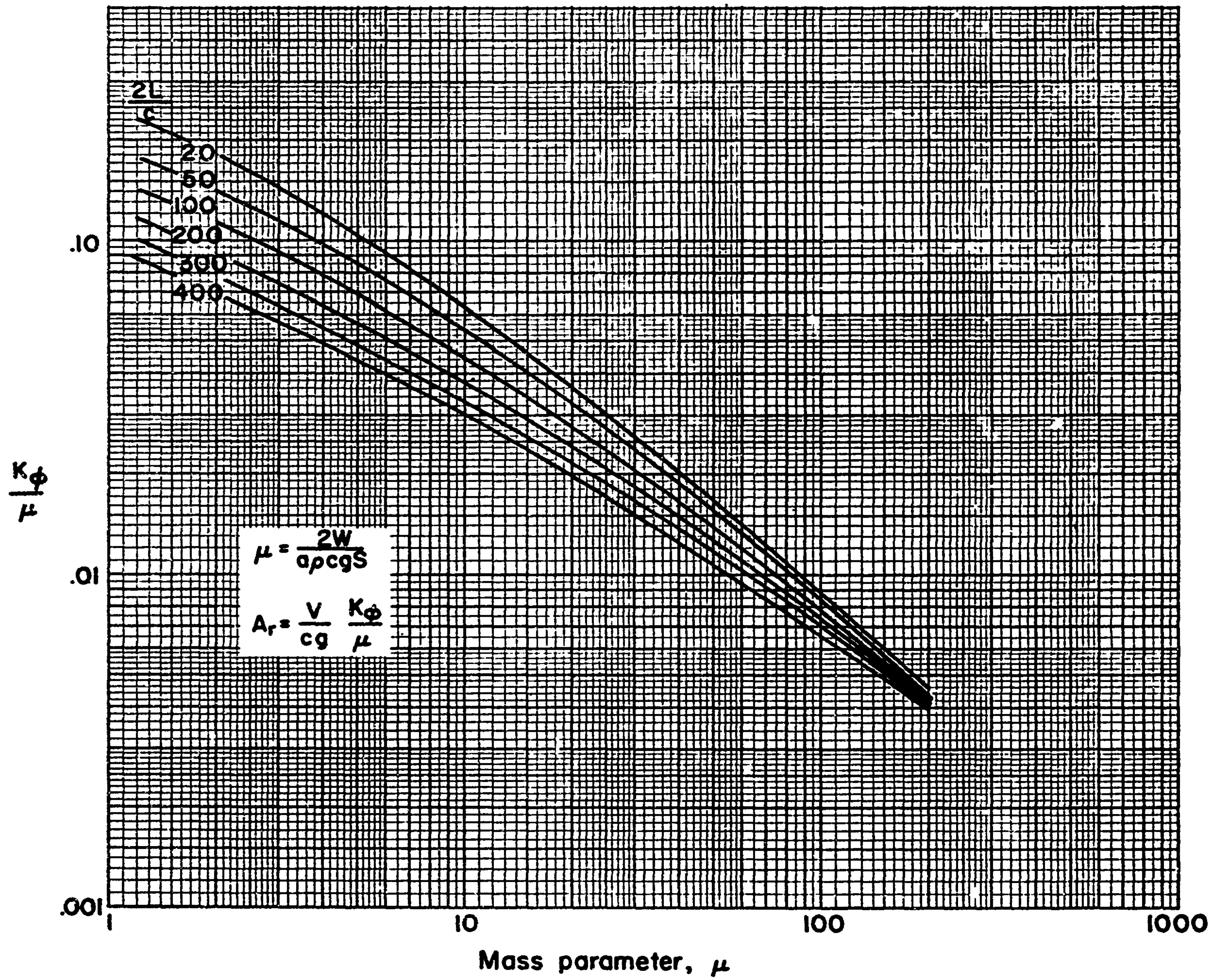


Figure 14. Variation of $\frac{K_\phi}{\mu}$ with μ

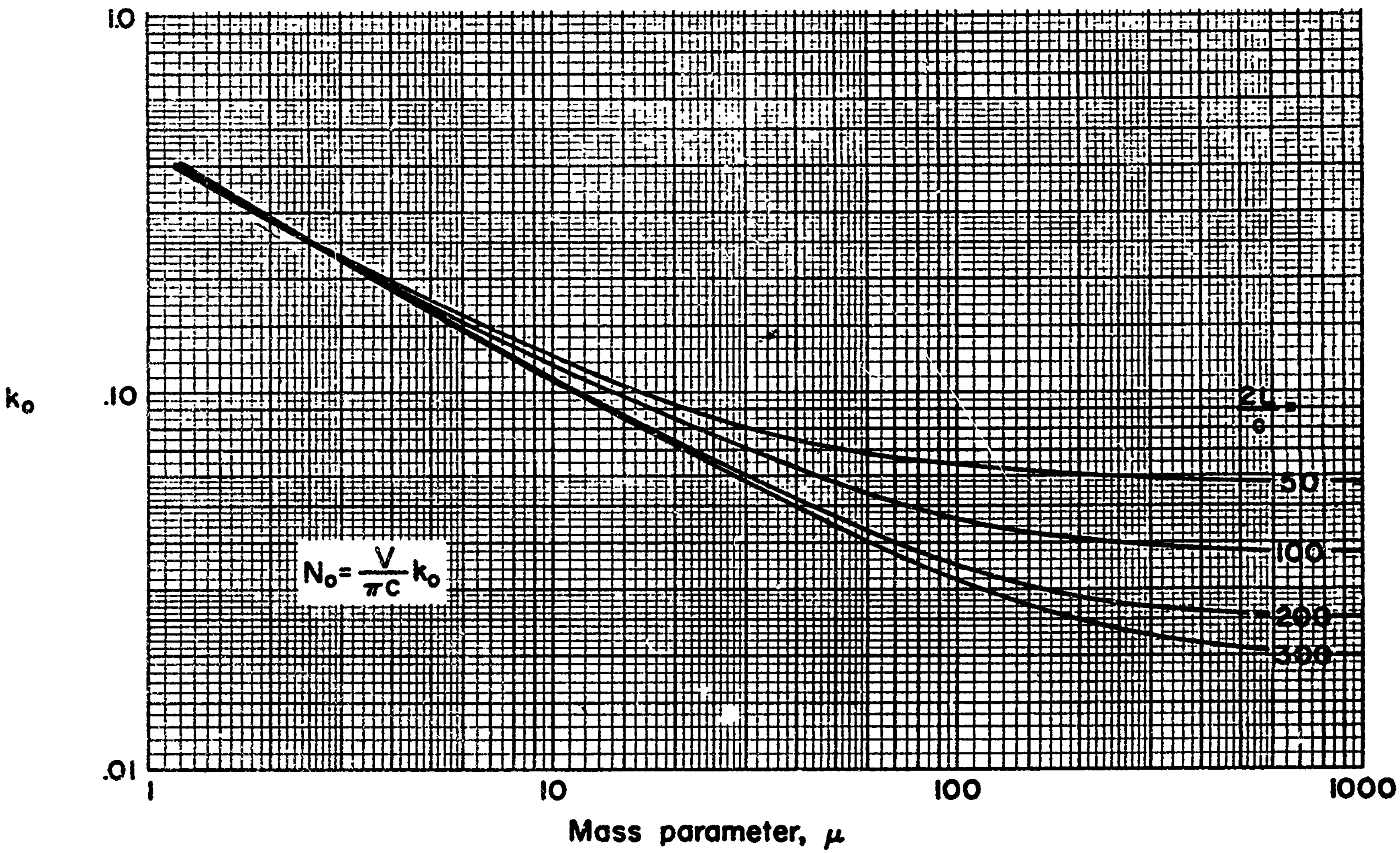


Figure 15. Zero-Crossing Values k_o

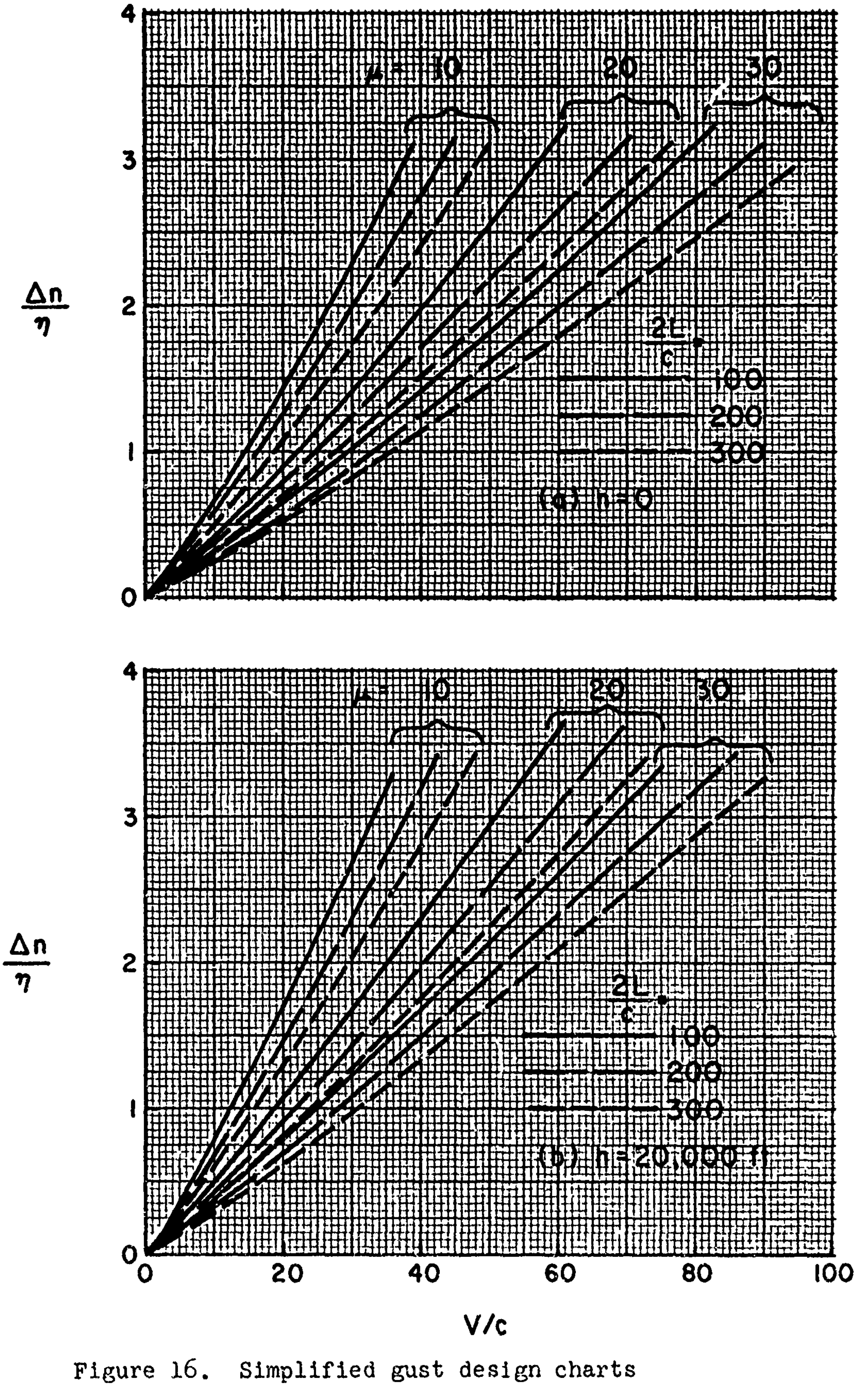


Figure 16. Simplified gust design charts